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Shum

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(54) **RECTIFIER STRUCTURES FOR AC LED SYSTEMS**

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H01L 29/18 (2006.01)
H01L 33/00 (2010.01)

(52) **U.S. Cl.**
USPC **257/88**; 257/100

(58) **Field of Classification Search**
USPC 257/88, 100
See application file for complete search history.

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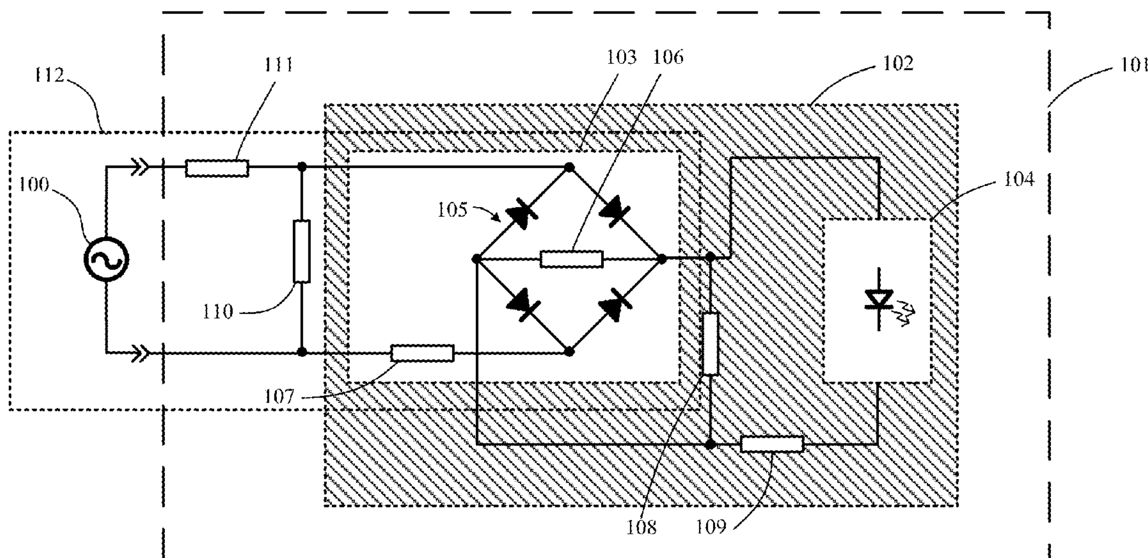
(57) **ABSTRACT**

A space efficient arrangement of at least one LED with a rectifying element and a current limiting element forms a compact module that can be powered using an AC voltage source.

20 Claims, 12 Drawing Sheets



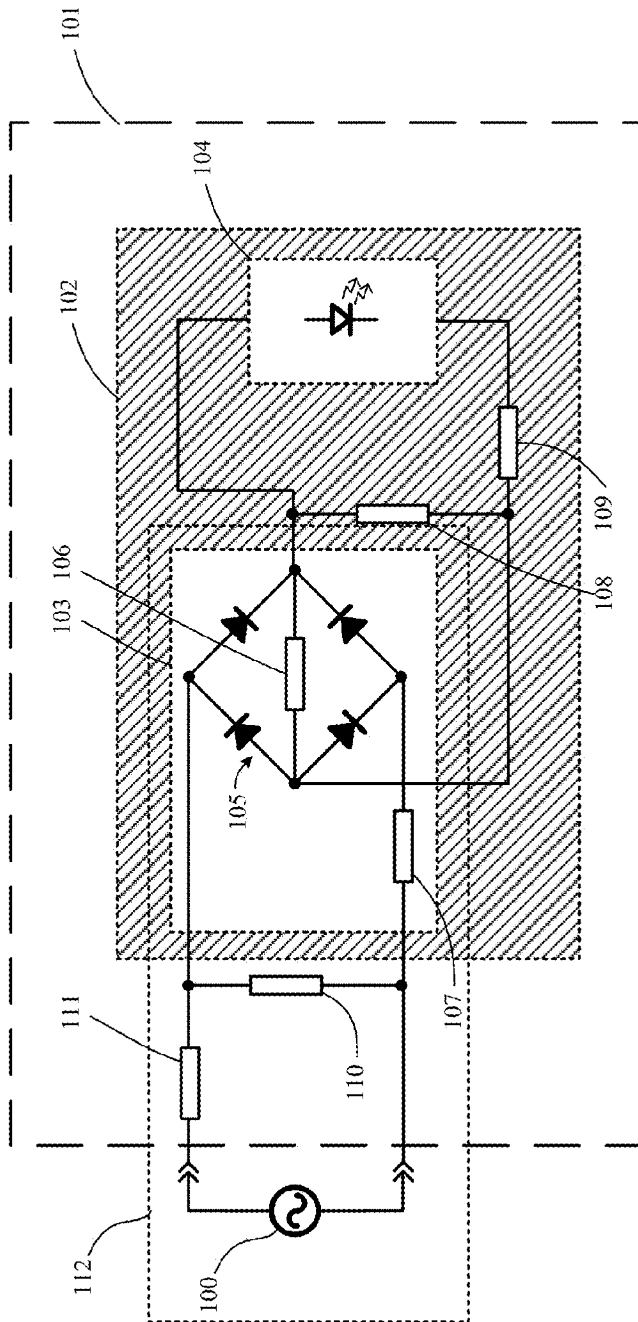


Fig. 1a

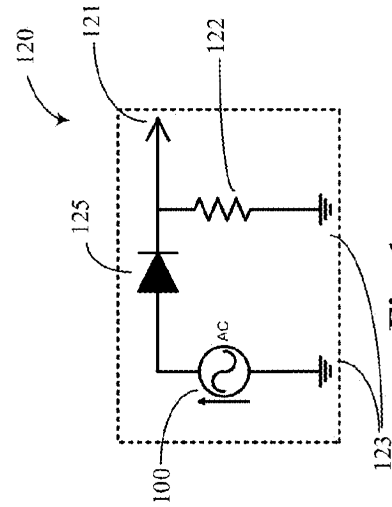


Fig. 1c

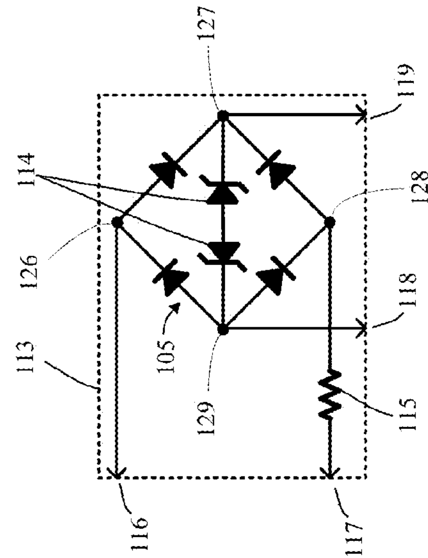


Fig. 1b

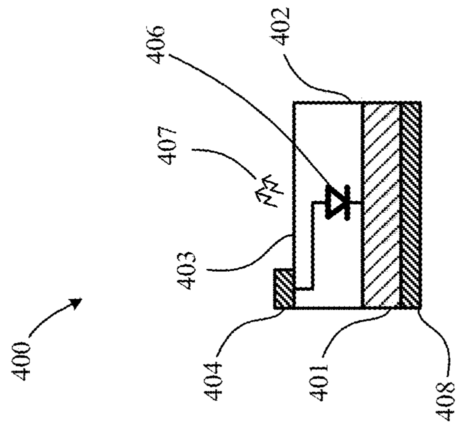


Fig. 4

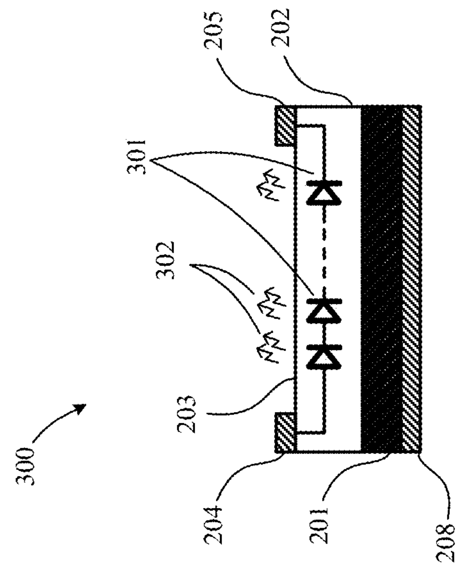


Fig. 3

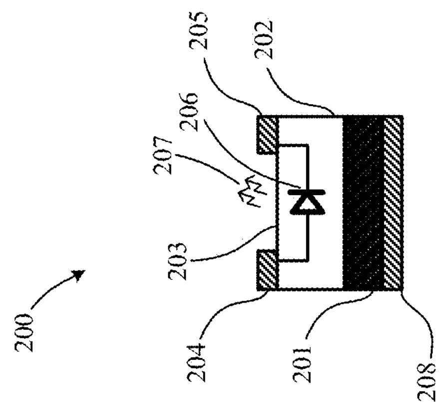


Fig. 2

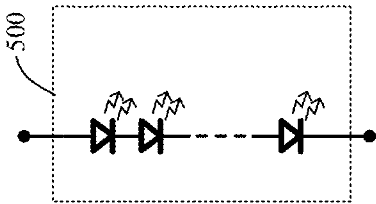


Fig. 5a

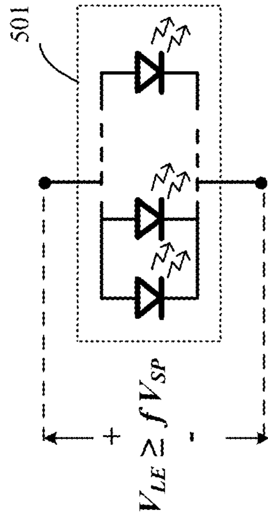


Fig. 5b

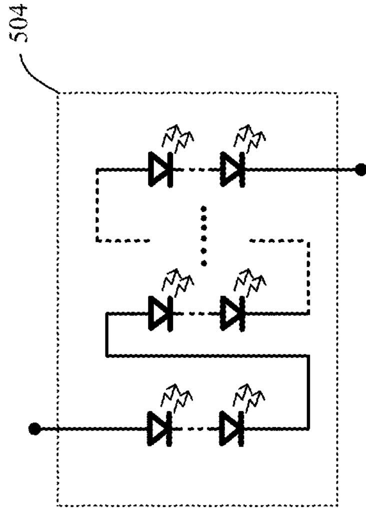


Fig. 5c

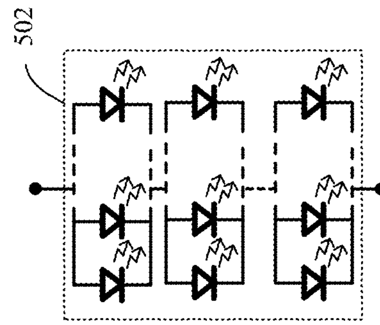


Fig. 5d

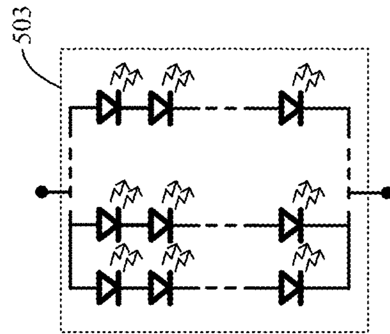


Fig. 5e

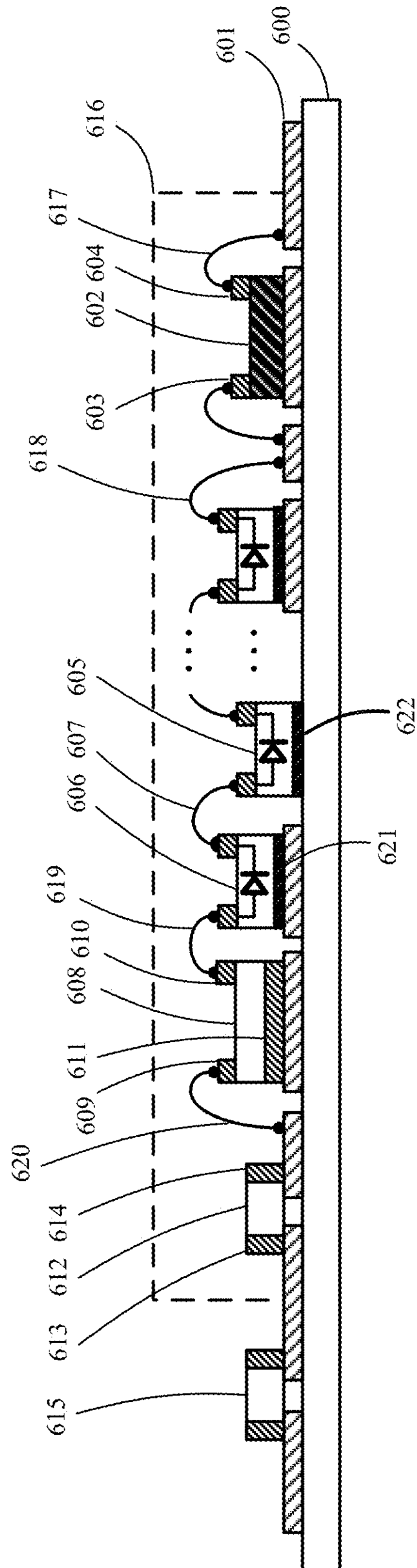


Fig. 6

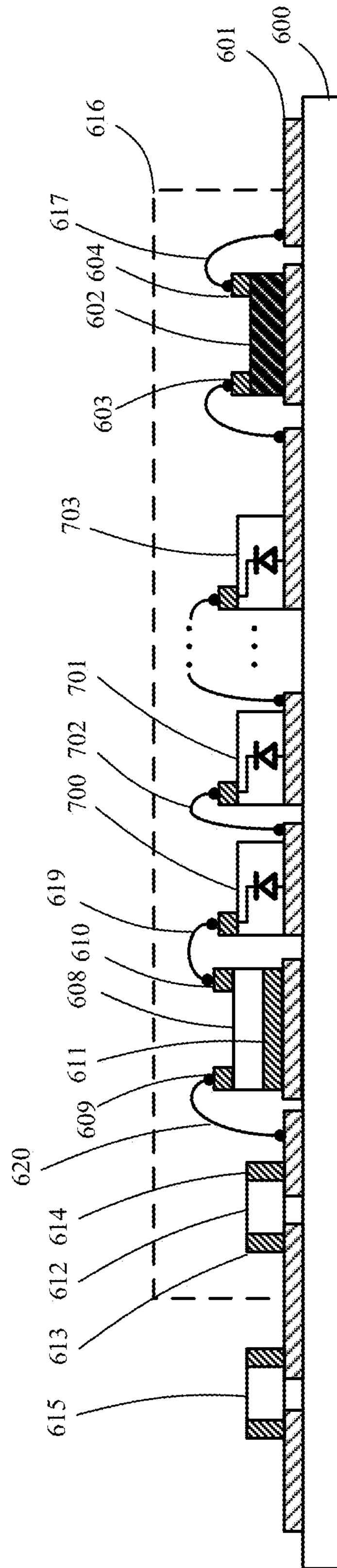


Fig. 7

600
601
616
617
602 604
603
803
802
801
800
619
610
608
611
609
620
614
612
613
615

Fig. 8

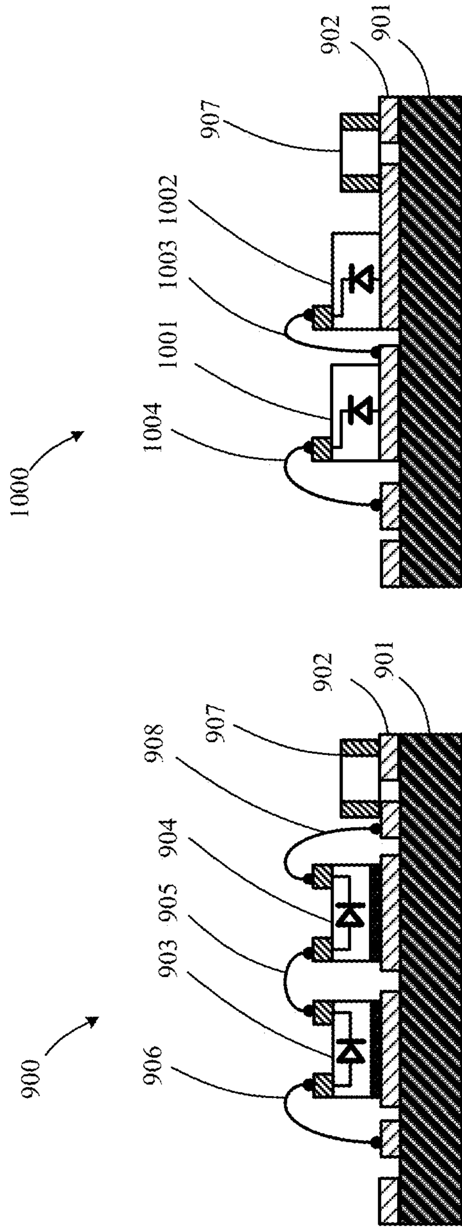


Fig. 10

Fig. 9

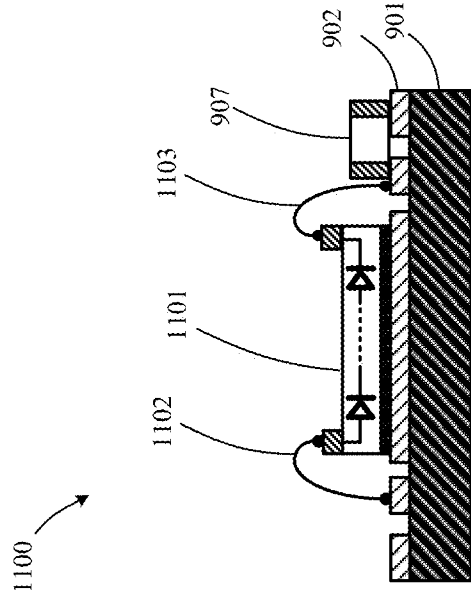


Fig. 11

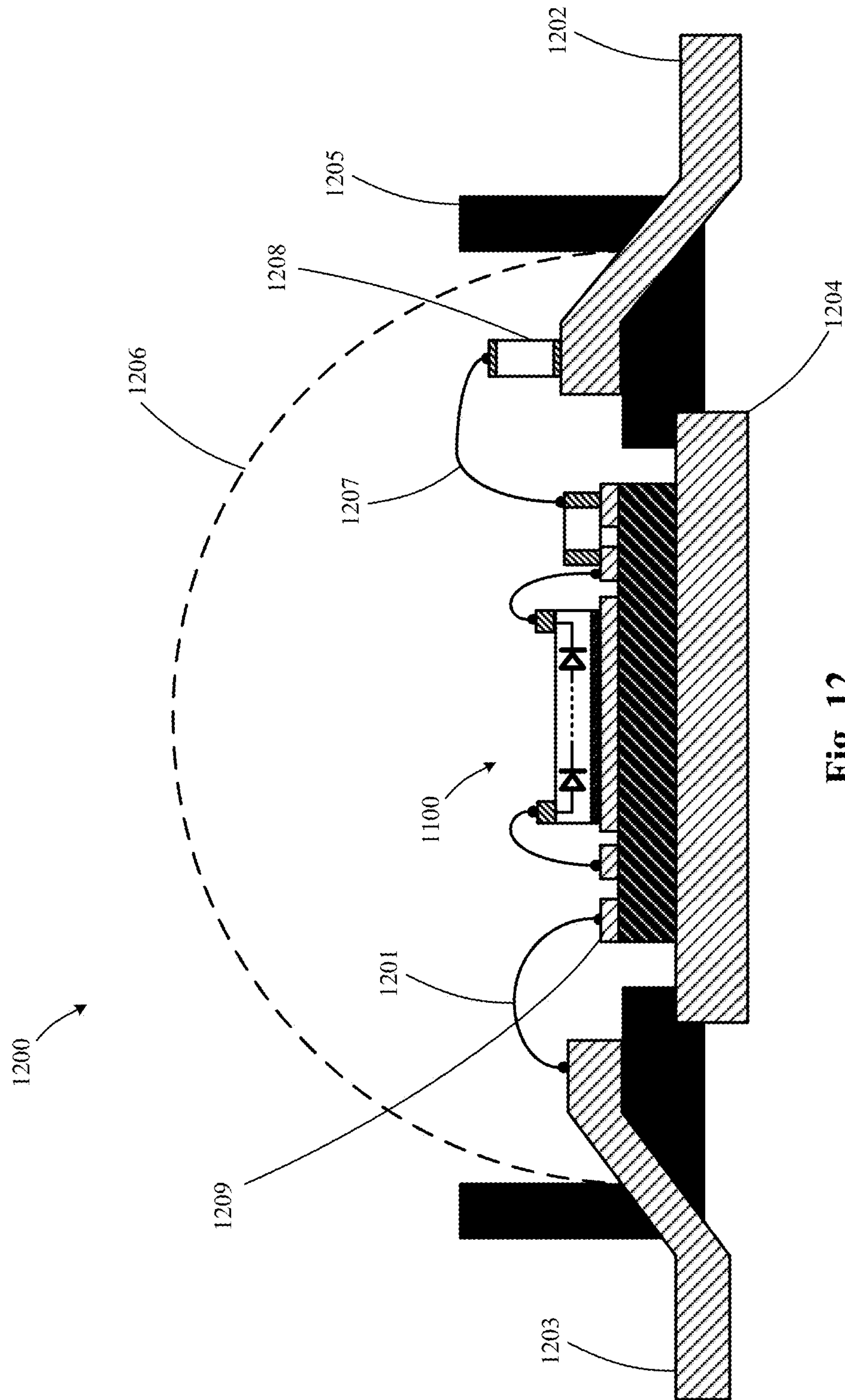


Fig. 12

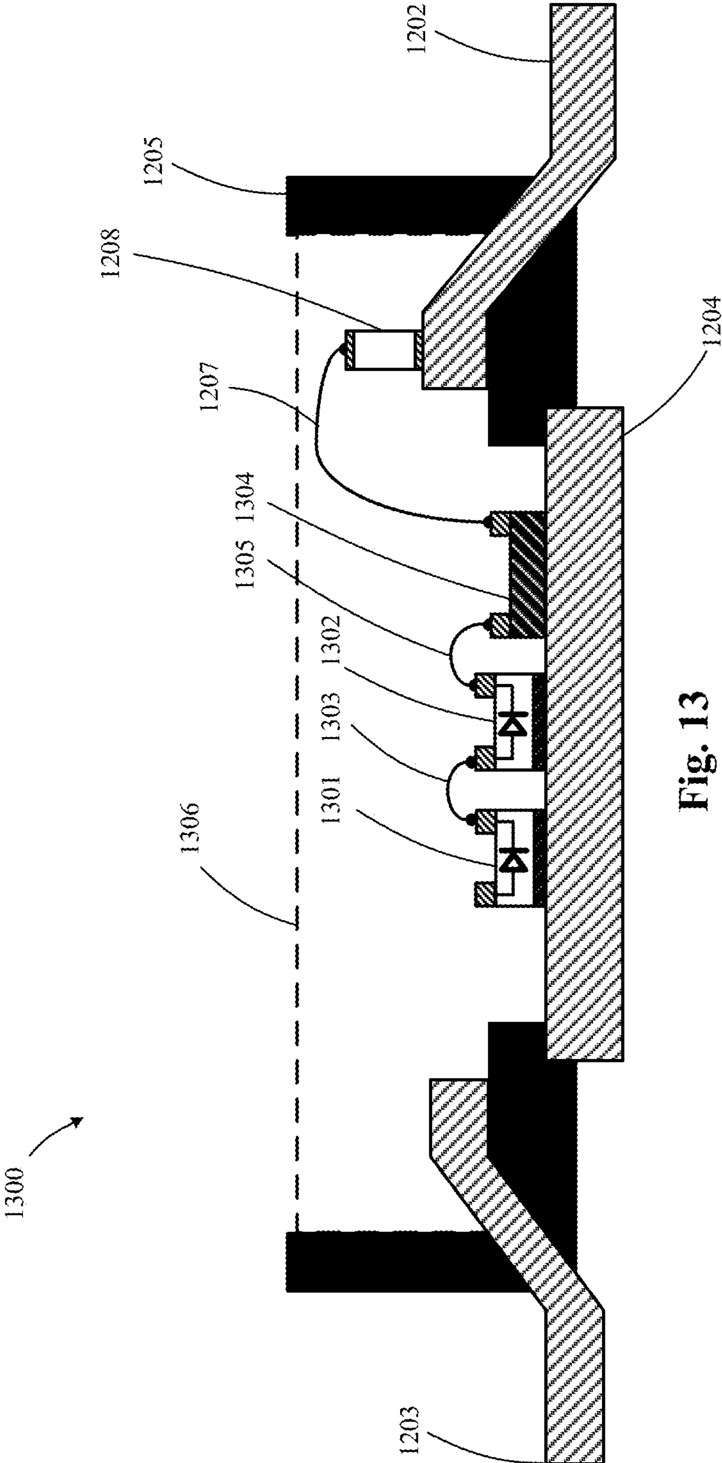


Fig. 13

1400
1401
1402
1403
1404
1405
1406
1407
1408

Fig. 14

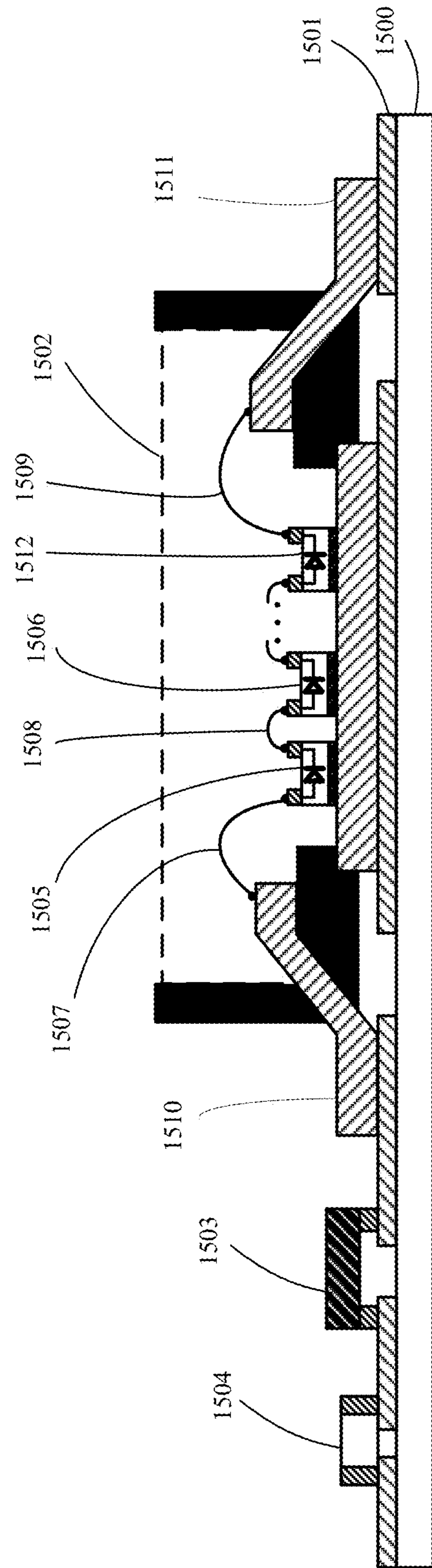


Fig. 15

1500
1501
1511
1603
1600
1601
1602
1510
1503
1504

Fig. 16

RECTIFIER STRUCTURES FOR AC LED SYSTEMS

BACKGROUND OF THE INVENTION

This invention relates to the field of lighting and illumination. More particularly, this invention relates to a technique to increase the efficiency of power electronics for light emitting diodes.

Since the development of the incandescent light bulb, electric lighting has become widely adopted and is considered one of the inventions which has had the most profound impact on human society. Lighting allows people to do many activities in the night hours which they would otherwise not be able to do without such lighting. Modern society depends on electric lighting.

Despite the success of modern electric lighting, there continues to be a need for improvements in electric lighting. For example, it is desirable to increase lighting brightness, improve efficiency, reduce power consumption, reduce heat output, and improve other characteristics of lighting sources.

LEDs outperform traditional lighting such as incandescent, fluorescent, or high intensity discharge (HID) lighting in power efficiency and or longevity. Although LEDs have been used as indicator lights, traffic signals, car tail lights, and similar applications, LEDs are generally not being used for general illumination due to a number of problems.

Some challenges to the adoption of LEDs for general illumination include the color or color temperature of LED illumination, brightness over time, power requirements, and high cost. Compared to incandescent and other lighting which use alternating current (AC) power, LEDs use direct current (DC) power. So, an LED lighting system need extra space to accommodate power electronics or power supply that converts AC power to DC power. In LED versions of incandescent lamps with form factors such as A, PAR, MR, R, BR, the need to accommodate the extra electronics is a major challenge.

Therefore, there is a need for LED lighting systems packaged with compact power electronics.

BRIEF SUMMARY OF THE INVENTION

A space efficient arrangement of at least one LED with a rectifying element and a current limiting element forms a compact module that can be powered using an AC voltage source.

In one embodiment, a bare silicon die containing the rectifying element is assembled with at least one LED to produce a compact module that can be powered with an AC voltage. In another embodiment, at least two LEDs are packaged together with an external rectifying element and a current limiting element to produce a compact module that can be powered with an AC voltage.

Additionally, this invention elaborates on how further space saving and assembly simplicity can be accomplished by incorporating additional functionality into the silicon rectifier die such as electrostatic discharge diodes (ESD diodes), limiting resistors, Zener diodes, surge protectors, and others.

In an implementation, a system includes: a first die including a light emitting diode with a light emitting surface; and a second die including a rectifier, where the rectifier of the second die is electrically connected to the light emitting diode of the first die. An encapsulation material is formed over the first and second dies, where the encapsulation material is a light transmitting medium.

In various embodiments, the first die is mounted on the second die. The first die includes at least one electrical contact on the light emitting surface. The second die is electrically connected to one electrical contact on the light emitting surface via a wire bond or other electrically conducted path. The second die can include at least one electric static discharge (ESD) protection diode. The second die can include at least one resistor. The first die includes at least two light emitting diodes.

The system can further include a third die including a light emitting diode, where the first and third dies are electrically connected together (e.g., via wire bond). The rectifying element can be fabricated from a silicon material.

In an implementation, a system including a packaged component includes: an AC power input to the packaged component; a first die including a first light emitting diode; a second die including a second light emitting diode; and a third die including a rectifier. The third die is electrically connected to the first and second die. The first and second dies are electrically connected to have or produce a combined forward voltage greater than the forward voltage either the first or second die. There is a current limiting element including a first terminal connected to the AC power input and a second terminal connected to the rectifying element.

In an implementation, a system includes a packaged component including: an AC power input to the packaged component; a first light emitting diode and a second light emitting diode on a first die, where the first and second light emitting diodes are electrically connected together. A rectifying element is connected to the first light emitting diode. And a current limiting element, having one terminal connected to the AC power input and a second terminal connected to the rectifying element.

The current limiting element can be a resistor. The current limiting element can be a capacitor. The first and second dies and the rectifying element are encapsulated together using a light transmitting medium.

The first and second dies are encapsulated together using a first medium and the rectifying element is encapsulated using a second medium, where the second medium is separate from the first medium.

In various implementations, the first medium can be light transmitting, while the second medium not light transmitting. The first die and the rectifying element are encapsulated together using a light transmitting medium. The first die is encapsulated using a first medium and the rectifying element is encapsulated using a second medium, where the second medium is separate from the first medium. The first and second light emitting diodes are connected together in series. The first and second light emitting diodes can be connected together in parallel.

Other objects, features, and advantages of the present invention will become apparent upon consideration of the following detailed description and the accompanying drawings, in which like reference designations represent like features throughout the figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1***a* is a schematic of the LED module of an alternating current drive circuit, constructed according to one embodiment of the invention, for supplying power to LEDs. FIG. **1***b* shows is a schematic of a full-wave rectifying element implementation. FIG. **1***c* shows a schematic for a half-wave rectifying element implementation.

FIG. **2** is a schematic of the functional components of a single lateral-structure LED formed on a semiconductor die.

FIG. **3** is a schematic of the functional components of multiple lateral-structure LEDs formed on a single semiconductor die.

FIG. **4** is a schematic of the functional components of a single vertical-structure LED formed on a semiconductor die.

FIGS. **5***a*-**5***e* show an example schematics of four alternative ways in which the LEDs of FIG. **4** may be arranged: in parallel, series, or a combination of both.

FIG. **6** is a diagram of a chip on board (COB) system embodiment of the invention containing multiple semiconductor dies, each with a lateral structure LED.

FIG. **7** is a diagram, similar to FIG. **6**, constructed according to another embodiment of the invention, containing multiple semiconductor dies, each with a vertical structure LED.

FIG. **8** is a diagram, similar to FIG. **6**, constructed according to another embodiment of the invention, containing a semiconductor die with multiple lateral structure LEDs.

FIG. **9** is a diagram of another embodiment of the invention, containing multiple semiconductor dies, each with a lateral structure LED.

FIG. **10** is a diagram, similar to FIG. **9**, of a LED system containing multiple semiconductor dies, each with a vertical structure LED, mounted on a silicon die.

FIG. **11** is a diagram, similar to FIG. **9**, of a LED system containing a semiconductor die with multiple lateral structure LEDs, mounted on a silicon die.

FIG. **12** is a diagram of a LED system mounted on a silicon die and incorporated into a lead frame package with a convex lens.

FIG. **13** is a diagram, similar to FIG. **12**, of a LED system mounted on a silicon die and incorporated into a lead frame package with a flat lens.

FIG. **14** is a diagram, similar to FIG. **12**, constructed according to another embodiment of the invention, is a LED system incorporated into a lead frame package with electrical leads.

FIG. **15** is a diagram of a LED system containing multiple semiconductor dies incorporated into a lead frame package, and then mounted on an electrical circuit.

FIG. **16** is a diagram, similar to FIG. **15**, of a LED system incorporated into a lead frame package with a convex lens, and then mounted on an electrical circuit.

DETAILED DESCRIPTION OF THE INVENTION

It is the object of this invention to provide a compact scheme to accommodate LEDs, rectifier and their associated components.

FIG. **1***a* is a schematic diagram showing a light emitting diode (LED) or light emitting element module **101** according to one embodiment of the present invention. LED module **101** contains an arrangement of LEDs **104** with at least one LED, and a bare silicon die **103** containing a rectifying element **105**. Arrangement of LEDs **104** and bare silicon die **103** are encapsulated within a light-transmitting medium **102**. Arrangement of LEDs **104** contains at least one semiconductor die, which contains at least one LED. By incorporating bare silicon die **103** and the LED semiconductor die together, the size of the system is reduced.

Optional components **106** and **107** such as ESD diodes, resistors, and capacitors may be formed on bare silicon die **103** along with rectifying element **105**. There may also be other components **108** or **109** such as capacitors, inductors, resistors, and diodes outside silicon die **103**, but within light-transmitting medium **102**. Optionally, there may be components **110** or **111** such as resistors, capacitors, and inductors, outside light-transmitting medium **102**, but within LED module **101**. The consolidation of these additional components, enables further space and cost saving. An external alternating current (AC) power source **100** with two inputs is electrically connected to power LED module **101**.

FIG. **1***b* shows another embodiment of rectifying element **105** from FIG. **1***a*, fabricated on silicon die **103**. Rectifying element **105** can be a full- or a half-wave rectifier. In this example, silicon die **113** with a full-wave rectifier also contains a resistor **115**, and Zener diodes **114** connected in series and of opposite polarity at the outputs **118 119** for ESD protection. If there are resistors, they are connected between the input **116** or **117** and one of the input nodes **126** or **128**. If there are Zener diodes, they should be connected between the output nodes **129** and **127**. One example is connecting two Zener diodes of opposite orientation in series. The silicon die has electrical contact inputs **116** and **117** and outputs **118** and **119** to allow for external electrical connections.

Full-wave rectifier **105** may be replaced by a half-wave rectifier, such as the one pictured in FIG. **1***c*. This is done by replacing region **112** by the module **120**. The half-wave rectifier is formed by connecting AC source **100**, a diode **125**, and an equivalent resistor **122**. Equivalent resistor **122** is optional and can be omitted. The positive end of AC source **100** is connected to the positive end of diode **125**. The negative end of AC source **100** is connected to the ground **123**. The negative end of diode **125** is connected to one end of resistor **122**. The other end of resistor **122** is connected to ground **123**. The output **121** goes to arrangement of LEDs **104** as before.

Arrangement of LEDs **104** is intended to be very general with no restriction on the type of LEDs, mixture of different LEDs, type or mixture of packaging, arrangement of electrical connections, and others. This will be discussed in FIG. **5**.

The LED can be fabricated of any semiconducting material, as long as the passage of electricity through the diode junction (**104**) results in the emission of light. For example, the LED semiconducting material may consist of compounds composed of group III (e.g., aluminum, gallium, and indium) and group V elements (e.g., phosphorous, arsenic, and antimony).

FIGS. **2**-**4** show examples of LED device structures, in which the light emitting surface also has at least one electrical contact **204**, **205**, or **404**. The contacts may be formed during microfabrication by using photolithography to create a window, leaving behind the two "islands" that are the metal contacts. A standard fabrication process for creating the metal contacts and the remainder of aspects of FIGS. **2** through **4** may be used.

FIG. **2** shows a single lateral structure LED **206** formed on the semiconductor die **200**. The semiconductor die **200** contains a layer of semiconductor material **202** and an electrically insulating layer **201** on which may be attached a lower metal layer **208**. The light transmitting surface **203** permits light to be emitted **207**. The light transmitting surface also has two electrical contacts **204** and **205**. Light may be generated when electricity is passed between contacts **204** and **205**, and there is a proper bias meeting the forward voltage requirement of LED **206**. Lower metal layer **208** is optional and is suitable for soldering. For example, the materials selected may be gallium nitride (GaN) for semiconducting layer **202**, sapphire for insulating layer **201**, chromium or titanium over coated with nickel then gold for bottom metal layer **208**, and chromium coated with nickel and gold for electrical contacts **204** and **205**. FIG. **2** is intended to show the schematic functional components but not the internal semiconducting layers.

FIG. **3** shows an alternate implementation of a LED similar to **200**, except in this implementation, the semiconductor die **300** contains more than one lateral structure LED **301**. Like

200, the semiconductor die 300 has a light transmitting surface 203, that permits light be emitted 302 when the proper bias is applied using electrical contacts 204 and 205 located on light transmitting surface 203. The exact electrical connections between the LEDs 301 is intended to be very general such as but not limited to the series, parallel, and a combination of series and configuration shown in FIG. 5 and discussed below. Forming multiple LEDs 301 in series on a single semiconductor die may be used to increase the forward voltage of the device in a very compact space. FIG. 3 is intended to show the schematic functional components but not the internal semiconductor layers.

FIG. 4 shows an implementation of a semiconductor die containing a vertical structure LED, in which there is a top electrical contact 404 and a bottom electrical contact 408. The LED is formed in the semiconductor material 402 with an electrically conducting substrate 401. The light transmitting surface 403 permits light to be emitted 407. Light transmitting surface 403 also has an electrical contact 404. In this illustration, light is emitted when contacts 404 and 408 are properly biased (i.e., there is a proper voltage difference between the metal contacts, stipulated by the forward voltage of the LED). In an alternate construction, the polarity of contacts 403 and 408 may be reversed. The semiconducting material 402 can be made from gallium nitride bonded to electrically conducting silicon layer 401. Electrical contacts 404 and 408 can be thin layers of chromium over coated with nickel then gold. FIG. 4 is intended to show the schematic functional components but not the internal semiconductor layers.

FIGS. 5*a*-5*e* shows some examples of possible configurations for the arrangement of LED 104 where one or more LEDs are connected in an electrical arrangement to as to achieve the necessary forward voltage and current characteristics. In one embodiment, more than one LED is electrically connected to achieve a higher forward voltage than the forward voltage of any single LED itself. Increasing the forward voltage is advantage to reduce current draw while maintaining a fixed overall power. System with low forward voltage and high current of the same fixed power are electrically inefficiency due to the resistive loss in the wiring and other electrical connections. In addition the combined higher forward voltage of the LED arrangement typically provided for an improved power factor and efficiency characteristics for the LED system. In one embodiment, the forward voltage of the LED arrangement is greater than or equal to 35 percent, greater than or equal to 50 percent, or equal to 70 percent of the peak AC voltage. The benefits of increasing forward voltage for power factor and efficiency are the subject matter of another patent application, U.S. patent application Ser. No. 12/494,685, filed Jun. 30, 2009, which is incorporated by reference along with all other references cited in this patent. U.S. patent application Ser. Nos. 12/494,705, filed Jun. 30, 2009; 12/494,746, filed Jun. 30, 2009; 12/494,787, filed Jun. 30, 2009; 61/186,281, filed Jun. 11, 2009; 61/219,208, filed Jun. 22, 2009; and 61/219,571, filed Jun. 23, 2009, are also incorporated by reference.

Arrangement of LEDs 104 may be connected in series 500 (i.e., all the LEDs are oriented in the same direction, and the end of one LED L_1 is connected to the end of another LED L_2, but the other end of LED L_1 cannot be connected to the other end of LED L_2), in parallel 501 (i.e., all the one end of all the LEDs, e.g., the p side, are all form one node, while the other end of all the LEDs, e.g., the n sides, all the n side are connected to another node), or series-parallel combinations. Groups of parallel LEDs 501 may then be connected in series 502.

Likewise, groups of series LEDs 500 may then be connected in parallel 503. This invention encompasses any combination of LEDs. Additionally, and array of n LEDs may also connected in series (i.e., all the LEDs are oriented in the same direction, and the end of one LED L_1 is connected to the end of another LED L_2, but the other end of LED L_1 cannot be connected to the other end of LED L_2).

The arrangement of LEDs 500, 501, 502, 504, or 504 can be multiple individual LED dies on a substrate such as chip on board, or all the LEDs may be formed on the same die.

FIG. 6 shows a chip on board (COB) embodiment of the invention containing an electrically insulating substrate 600 with a conductive pattern 601. The embodiment contains at least one lateral semiconductor die 605 or 606 of the type in FIG. 2 and at least one silicon die 602. The silicon die 602 contains at least one rectifying element. The LED die is electrically connected to the silicon die through the conductive pattern 601 or wire bonds 618, or both. Whenever a wire bond connection is mentioned in this document, it refers to the connection made by the wire bond such that there is an electrical connection formed between the metal contact 204, 205, or 404 of one die with the metal contact 204, 205, or 404 of another die. LED die 605 and 606 and silicon die 602 are encapsulated in a light transmitting medium 616.

Substrate 600 may be fabricated from a ceramic material such as alumina, aluminum nitride, or beryllium oxide. Conductive pattern 601 may be a thin coating of a metal such as a layer of chromium, over coated with nickel, then over coated with gold. Conductive pattern 601 can also be fabricated using a thick film process such as screen printing. These metal layers are typically less than a few microns thick. Packaging technologies such as thick film, thin film, and thick copper metallization are document chapters 1-5 of textbook "Hybrid Microelectronics Handbook" by Harper & Sergent, published by McGraw-Hill Companies, 2, Jul. 1, 1995, and is incorporated by reference.

Alternatively substrate 600 and conductive pattern 601 may be fabricated from standard PCB or flex circuit processes. Substrate 600 can be made of FR4, flexible polyamide, or other materials from in the printed circuit boards (PCB) industry. Conductive pattern 601 is typically a copper foil laminated onto the substrate and patterned.

In another embodiment, substrate 600 need not be entirely insulating, but may be made of a metal material such as aluminum with a thin insulating layer to which conductive pattern 601 is bonded. Such construction is commonly known as metal clad board (MCB) or metal clad PCB (MCPCB) and available from companies such as Bergeist under the trade name THERMAL CLAD. In an alternate implementation of the substrate, the thin insulating layer can be aluminum oxide on an aluminum base. The conductive pattern can be screen printed onto the insulating aluminum oxide layer. Such substrates go by the trade name ANOTHERM, available from the IRC Advanced Film Division, a TT electronics company.

Encapsulation 616 is used to protect the LED dies 605 and 606, the silicon die 602 and wire bonds 607, 617, 618, 619, and 620. Encapsulation 616 transmits light but need not be entirely transparent. Encapsulation 616 may contain phosphors particles or light dispersing particles such as silica or titanium dioxide. Encapsulation 616 can be made of silicone, PMMA (polymethyl methacrylate), acrylic, polycarbonate, epoxy, and others.

There may be other electrical components 608 and 612 within the encapsulant such as resistors, capacitors, inductors, diodes, and the like. Component 612 is a surface mount component (SMC) with electrical contacts 613 and 614 attached to conductive pattern 601 using a conductive adhe-

sive such as silver epoxy or solder. Component **608** has top contacts like **609** and **610** and bottom contacts like **611** where the top contacts are connected to other components via wire bonds **619** and **620** and the bottom contact **611** is bonded via conductive adhesive or solder to conductive pattern **601**.

Semiconductor die **606** can be bonded to conductive pattern **601** using an adhesive such as silver epoxy or a solder. Alternatively, semiconductor die **605** can be bonded directly to insulating substrate **600** using an adhesive that is preferably thermally conductive.

There may be other electrical components **615** bonded to the conductive pattern **601** or substrate **600** but outside encapsulation **616**.

FIG. **7** shows an alternative implementation similar to FIG. **6**. Lateral LED die **605** and **606** are now replaced with at least one vertical structure LED die **700**, **701**, or **703** of the construction of FIG. **4**. LED die **700** has top contact **404** and bottom contact **408**. LED die **700** may electrically connected to another LED die **702** by connecting the top contact of one die **701** with the bottom contact of another die **700** via a wire bond **702**. The LED may also be connected to other types of components **602** or **608**, again be connecting any free contact (the top in some cases **700**, the bottom in other cases **703**) with the contact of another die via a wire bond **619** or **603**. LED bottom contact **408** is electrically connected to conductive pattern **601** during the attachment process. The attachment of LED die **700** can be done using an electrically conductive adhesive such as silver epoxy or solder.

FIG. **8** shows an alternative implementation similar to FIG. **6** but with at least one lateral semiconductor die **800** containing at least two LEDs of the construction discussed previously for FIG. **3**. LED die **800** is either bonded to the conductive pattern **601** as shown using conductive epoxy or solder, or alternatively LED die **800** is directly bonded to the insulating substrate **600** using an adhesive, in the same fashion as for **622**. The adhesive is preferably thermally conductive. LED **800** has two contacts in the top layer **204** and **205** that is used to connect to other components. LED **800** may be connected to some components **608** via wire bond **619**, by forming a connection between the metal contact of one die with the metal contact of another component. The LED may also be connected to other components **602** by forming a connection with a portion of the electrical conductive pattern **802** via the wire bond **801**. The component to which LED **800** is connected must also form a connection via wire bond **803** to the same portion of the electrical conductive pattern **802** to ensure an electrical connection.

FIGS. **9-11** are constructed according to another embodiment of this invention, in which at least one semiconductor die, containing at least one LED, is mounted directly on top of the silicon die. The silicon die contains at least one rectifying element. The semiconductor die has a light emitting surface that also contains at least one electrical contact (i.e., it may be of the lateral or vertical construction).

FIG. **9** shows one implementation **900** using at least one lateral semiconductor die **903** or **904** of the construction previously described in FIG. **2**, bonded to the silicon die **901** using a conductive epoxy or solder. Silicon die **901** has an electrically conductive pattern **902**. The conductive pattern can be formed using a thin film metallization process. The metallization layers can be chromium, nickel, and gold. As previously described, a standard technique for metallization such as chemical vapor deposition or sputtering can be used.

LED die **903** or **904** can be bonded with an electrically conductive adhesive or soldered to the electrical pattern **902**. The LED can alternatively be bonded using (preferably) a thermally conductive adhesive to silicon die **901**. The LED die **903** or **904** may be connected to each other via wire bonds **905** that connect the contact from one die to the contact of another die. The LED die **904** may also be connected to other components via wire bond **908** by connecting any free contact of the die to one region of the conductive pattern **902**, on which is bonded (i.e., electrically connected) the other component **907**. Wire bond **906** connects LED die **903** to the silicon die **901**.

Any number of additional components may be bonded to the silicon die. The other electrical components can be surface mountable components such as capacitors, resistors, inductors, or diodes (e.g., ESD, Zener, or any other type of diode), or any combination of these. The silicon die may itself contain other useful circuitry such as Zener diodes, resistors, or capacitors.

FIG. **10**, similar to FIG. **9**, shows another implementation **1000**, where at least one semiconductor die **1001** or **1002** contains a vertical structure LED of the construction previously described in FIG. **4** with a top electrical contact **403** and a bottom electrical contact **408**. Top electrical contact **403** may be connected to the electrically conductive pattern **902** via a wire bond **1003** or **1004**. This is how LED die **1001** and **1002** are connected to each other and the silicon die. Because the LED dies **1001** and **1002** are oriented with one contact at the top of the die and another on the bottom (bonded on the conductive pattern), other components **907** may be bonded to conductive pattern **902** to form electrical connections, if they reside in the same region of conductive pattern **901** as does LED die **1002**. The methods and properties of these components are the same as those in FIG. **9**, except the LED die **1001** and **1002**, as noted.

FIG. **11**, similar to FIG. **9**, shows another implementation **1100** where at least one semiconductor die **1101** contains at least two lateral structure LEDs previously described in FIG. **3**. LED die **1101** has contacts in the top layer connected to electrical pattern **902** via the wire bonds **1102** or **1103**. As described in FIG. **9**, LED die **1101** is connected to other components **907** via the wire bond **1103**, by connecting the contact of the LED and the region of conductive pattern **902** on which resides the other component **907**.

FIGS. **12**, **13**, and **14** depict the compact implementations of encapsulated lead frame packages with the LED modules **900**, **1000**, or **1100** and LED structures **200**, **300**, or **400** to support use of the invention in myriad applications. In other words, there is an abstraction that enables users of the invention to connect the leads of the package to an AC source to power the LED. The encapsulation does not need to be completely transparent as long as it supports transmission of light.

FIG. **12** shows LED module **1100** incorporated into a lead frame package **1200**. Alternatively LED module **1100** can be replaced with LED module **900** or **1000**. Lead frame package **1200** consists of a metal element **1204** and metal conductive leads **1202** and **1203**. LED module **1100** is bonded to metal element **1204** using a solder or an adhesive that is preferably thermally conductive. The lead frame elements **1202**, **1203**, and **1204** are electrically isolated from each other by electrically insulating material **1205**. A metal material such as Kovar or copper may be used for lead frame elements **1202**, **1203**, and **1204**, and a plastic may be used for insulating material **1205**. LED module **1100** is electrically connected to metal conductive leads **1202** and **1203** via wire bonds **1201** and **1207** by forming a connection between the contact of LED die of module **1100** and the conductive pattern **1209**. A connection must also be formed between conductive pattern **1209** and lead **1203**. Optionally, there may be other components **1208** such resistors, capacitors, and inductors, and

diodes (ESD or Zener) connected to the lead frame. LED module **1100** may be encapsulated within a convex lens **1206**.

FIG. **13** shows an embodiment of a LED module **1300** containing a lead frame package, at least one semiconductor die **1301** or **1302** and a silicon die **1304**, which are encapsulated by a flat lens **1306**, also a light transmitting medium. Silicon die **1304** contains at least one rectifying element. Semiconductor die **1302** is electrically connected other semiconductor die **1301** via wire bond **1303** or other components such as silicon die **1304** via wire bond **1305**. Semiconductor die **1301** or **1302** contains at least one LED of the construction previously described in FIG. **2**, **3**, or **4**. For example, Semiconductor dies **1301** and **1302** contain lateral or vertical structure LEDs of FIG. **2** or **3** and bonded to frame **1204** using a solder or an adhesive that is preferably thermally conductive.

FIG. **14** shows another implementation. LED module **1400** contains a lead frame package, at least one semiconductor die **1404** and silicon die **1405**, and are encapsulated **1403**. In this implementation of the lead frame package, there are electrical leads **1401** and **1402**. Lead **1401** also provides a mounting surface to bond semiconductor die **1404** and silicon die **1405**. LED die **1404** is electrically connected to other components **1405** (which may be other LED die) via wire bond **1406**. Silicon die **1405** is electrically connected to the leads **1401** and **1402** via wire bonds **1407 1408**. The LED is of the lateral type of FIG. **2** or **4**. In other implementations, vertical type LEDs may be used, and vertical LEDs may be used in combination with lateral type LEDs. Semiconductor die **1404** contains at least one LED of the construction previously described in FIG. **2**, **3**, or **4**. Convex encapsulation **1403** serves as an optically transmitting medium as well as a mechanical means to hold the leads **1401** and **1402**.

FIG. **15** shows an alternate compact implementation including at least one LED package **1502** (e.g., with lateral or vertical structured LEDs). The LEDs in the LED packaged are connected in series between an electrical terminal or lead **1510** and **1511**. Specifically, for example, the LED package has at least two LEDs **1505** and **1506** electrically connected together via wire bonds **1508**. First LED **1505** is connected to lead **1510** using a wire bond **1507** and to second LED **1506** using a wire bond **1508**. A last LED **1512** in the series is connected to lead **1511** using a wire bond **1509**.

A bottom layer **1500** is an insulating substrate. The layer above the bottom layer is a conductive pattern **1501**. LED package **1502**, a stand-alone rectifying element **1503**, and a current limiting element **1504** in its own package are bonded to this layer.

The components are bonded through soldering or an electrically conductive epoxy (e.g., silver epoxy). LED package **1502** is intended to be very general for the purposes of this invention, as long as it contains at least two LEDs. Other possible package types containing more than one LED are available from Cree, Osram, Lumileds, Nichia, and Bridgelux, and are incorporated by reference. The material and fabrication process for substrate **1500** and conductive layer **1501** can be PCB or MCPCB. All the processes and material for the previously described for insulating substrate **600** and conductive pattern **601** can be applied to insulating substrate **1500** and conductive pattern **1501**. The current limiting element **1504** is a capacitor or resistor **111** in series with the AC input source **100**.

FIG. **16** shows a variation of FIG. **15**, in which the module contains at least a package with a convex lens **1600**, the package contains at least one semiconductor die **1601**, which contains at least two LEDs of the type in FIG. **3**. The LEDs are electrically connected to each other and to the metal conductive leads **1510** and **1511** by wire bonds **1602** and **1603** in the manner described for FIG. **15**. All other properties of this embodiment of the figure are the same as those of FIG. **15**.

An LED requires DC current to function. A rectifier can be used to transform an AC voltage source into a DC voltage source. To limit the current from DC voltage source a current limiting component such as a resistor or capacitor in series with the AC voltage source can be used. The disadvantage is the additional space and cost necessary for the extra level of packaging where the LED and rectifier are attached to the PCB. In addition, for certain designs where multiple LEDs are required to achieve a higher forward voltage, significantly more space is required to accommodate the multiple individual LED packages.

Another technique is to use LEDs themselves as rectifiers. However in this implementation the LEDs must have good reverse voltage characteristics which may be difficult to achieve for high voltage applications. In another technique, two strings of LEDs are connected together in an inverse parallel arrangement. Each string of LED lights up on alternating halves of the AC cycle. A separate current limiting element such as a capacitor, or resistor, or both is usually placed in series. The advantage is the elimination of a separate silicon rectifier. However, now twice as many LEDs are necessary.

This description of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form described, and many modifications and variations are possible in light of the teaching above. The embodiments were chosen and described in order to best explain the principles of the invention and its practical applications. This description will enable others skilled in the art to best utilize and practice the invention in various embodiments and with various modifications as are suited to a particular use. The scope of the invention is defined by the following claims.

The invention claimed is:

1. A system comprising a packaged component comprising:

an AC power input to the packaged component;

a first die comprising a first light emitting diode;

a second die comprising of a second light emitting diode;

a third die comprising a silicon rectifying element,

wherein the third die is electrically coupled to the first and second die,

the first and second dies are electrically coupled to produce a combined forward voltage greater than the forward voltage of either the first or second die,

a first current limiting element, comprising a first terminal coupled to the AC power input and a second terminal coupled to the rectifying element, and

the first, second, and third dies are formed on a one side of a planar substrate; and

a second current limiting element, comprising a first terminal coupled to the rectifying element and a second terminal coupled to the second light emitting diode.

2. The system of claim **1** wherein the first current limiting element comprises a resistor.

3. The system of claim **1** wherein the first current limiting element comprises a capacitor.

4. The system of claim **1** wherein the first and second dies and the rectifying element are encapsulated together using a light transmitting medium.

5. The system of claim **1** wherein the first and second dies are encapsulated together using a first medium, and the rectifying element is encapsulated using a second medium, wherein the second medium is separate from the first medium.

6. The system of claim 5 wherein the first medium is light transmitting.

7. A system comprising a packaged component comprising:

an AC power input to the packaged component;

a first die comprising a first light emitting diode;

a second die comprising of a second light emitting diode; and

a third die comprising a silicon rectifying element,

wherein the third die is electrically coupled to the first and second die,

the first and second dies are electrically coupled to produce a combined forward voltage greater than the forward voltage of either the first or second die,

a current limiting element, comprising a first terminal coupled to a first node of the rectifying element and a second terminal coupled to a second node of the rectifying element,

the first and second dies are encapsulated together using a first medium, and the rectifying element is encapsulated using a second medium, wherein the second medium is separate from the first medium, and

the second medium is not light transmitting.

8. The system of claim 6 wherein the first die and the rectifying element are encapsulated together using a light transmitting medium.

9. The system of claim 1 wherein the first die is encapsulated using a first medium and the rectifying element is encapsulated using a second medium, wherein the second medium is separate from the first medium.

10. The system of claim 1 wherein the first and second light emitting diodes are coupled together in series.

11. The system of claim 1 wherein the first and second light emitting diodes are coupled together in parallel.

12. The system of claim 7 wherein the current limiting element comprises a resistor that is encapsulated in medium is not light transmitting.

13. A system comprising a packaged component comprising:

an AC power input to the packaged component;

a first die comprising a of a first light emitting diode;

a second die comprising of a second light emitting diode; and

a third die comprising a silicon rectifying element rectifier, wherein the third die is electrically coupled to the first and second die,

the first and second dies are electrically coupled to produce a combined forward voltage greater than the forward voltage of either the first or second die,

a current limiting element, comprising a first terminal coupled to the AC power input and a second terminal coupled to the AC power input,

the first, second, and third dies are formed on a one side of a planar substrate, and

the first, second, and third dies are encapsulated together using a light transmitting medium.

14. The system of claim 13 wherein the light transmitting medium comprises a convex lens above the surface of the first, second, and third dies.

15. The system of claim 13 wherein the AC power input is coupled to the third die via a first wire bond, the third die is coupled to the first die via a second wire bond, and the first die is coupled to the second die via a third wire bond.

16. The system of claim 13 wherein the first die comprises a third light emitting diode coupled in series with the first light emitting diode.

17. The system of claim 13 wherein the first terminal of the current limiting element is coupled to a positive electrode of the AC power input and the second terminal of the current limiting element is coupled to a negative electrode of the AC power input.

18. The system of claim 7 wherein the second terminal of the current limiting element is coupled to the first light emitting diode.

19. The system of claim 7 wherein the current limiting element is a first the current limiting element, and the system comprises:

a second current limiting element, comprising a first terminal coupled to the rectifying element and a second terminal coupled to the second light emitting diode.

20. The system of claim 1 wherein the first terminal of the second current limiting element is coupled to the first light emitting diode.

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